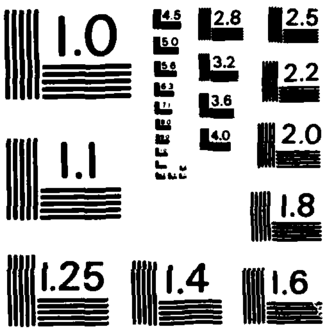
AD-A161 954 A BRIEF INTRODUCTION TO METAL MATRIX COMPOSITES MATERIALS AND TECHNOLOGY(U) METAL MATRIX COMPOSITES INFORMATION ANALYSIS CENTER SANTA BAR.. L A GONZALEZ 1/1

UNCLASSIFIED JAN 85 MMCIAC-000663 DLA900-80-C-4095 F/G 11/4 NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

2

AD-A161 954

MMCIAC No. 000663

A BRIEF INTRODUCTION
TO
METAL MATRIX COMPOSITES MATERIALS
AND TECHNOLOGY

Louis A. Gonzalez
Manager, MMCIAC

Presented At
Advanced Materials Workshop
California Polytechnic University
San Luis Obispò, CA
Dec. 10-11, 1984

DTIC
ELECTE
NOV 19 1985
S D
B

January 1985

DTIC FILE COPY

MMCIAC

DOD METAL MATRIX COMPOSITES INFORMATION ANALYSIS CENTER

OPERATED BY KAMAN TEMPO ● 816 STATE STREET ● P.O. DRAWER QQ
SANTA BARBARA, CALIFORNIA 93102-1479 ● PHONE: (805) 963-6497/455

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

85 11 12 117

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A161 954

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Statement A - Public Release
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) MMCIAC No. 000663	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Metal Matrix Composites Information Analysis Center 6b. OFFICE SYMBOL (If applicable) MMCIAC	7a. NAME OF MONITORING ORGANIZATION OUSDR&E Materials & Structures
6c. ADDRESS (City, State, and ZIP Code) c/o Kaman-Tempo P.O. Drawer QQ Santa Barbara, CA 93102	7b. ADDRESS (City, State, and ZIP Code) Room 3D1089 The Pentagon Washington, DC 20301-3081
8a. NAME OF FUNDING/SPONSORING ORGANIZATION DLA/DTIC 8b. OFFICE SYMBOL (If applicable) DTIC-AI	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DLA 900-80-C-4095
8c. ADDRESS (City, State, and ZIP Code) Cameron Station Alexandria, VA 22304-6145	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO.: 65802.5 PROJECT NO.: TASK NO.: WORK UNIT ACCESSION NO.:

11. TITLE (Include Security Classification)

(U) A brief Introduction ~~of~~ TO Metal Matrix Composites Materials and Technology

12. PERSONAL AUTHOR(S)

Louis A. Gonzalez

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
	FROM ____ TO ____	January 1985	12

16. SUPPLEMENTARY NOTATION Presented at Advanced Materials Workshop, California Polytechnic University, San Luis Obispo, CA, Dec. 10-11, 1984. Hardcopies available at no charge from MMCIAC, Kaman Tempo, P.O. Drawer QQ, Santa Barbara, CA 93102.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Metal matrix composites; Reinforcing fibers; aerospace materials; matrix materials; composite materials; structural composites.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This paper presents a general introduction to metal matrix composites, including discussions on reinforcement and matrix materials, physical and mechanical properties of the composites, applications of the materials, and fabrication methods. Keywords:

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

INTRODUCTION

Metal matrix composites (MMC's) are materials consisting of metal alloys reinforced with fibers, whiskers, particulates and wires. Because of their superior mechanical properties and unique physical characteristic such as low coefficients of thermal expansion, they are attractive for many structural and nonstructural applications.

The most notable production applications are the Space Shuttle boron/aluminum mid-fuselage struts and the Toyota diesel engine pistons. Estimated 1984 production for the latter is 350,000 demonstrating that MMC's can be cost effective and reliably mass produced.

Although there are many MMC's with widely different properties, it is possible to cite some general advantages of these materials over monolithic (unreinforced) metals and polymer matrix composites.

Compared to monolithic metals, metal matrix composites have:

- higher strength-to-density
- higher stiffness-to-density
- lower coefficients of thermal expansion
- better elevated temperature properties
  - higher strength
  - lower creep
  - better creep rupture resistance

Accession For
NTIS GRA&I ✓
DTIC TAB ☐
Unannounced ☐
Justification
PER CALL JC
By
Distribution/
Availability Codes
Dist | Avail and/or Special
A-1

QUALITY INSPECTED 3

The advantages of MMC's over polymer matrix composites are:

- higher temperature capability
- fire resistance
- higher transverse stiffness and strength
- no moisture absorption
- higher electrical and thermal conductivities
- better radiation resistance
- no outgassing
- whisker-and particulate-reinforced MMC's can be fabricated with conventional metal working equipment

The disadvantages of metal matrix composites are:

- higher cost
- technology relatively immature
- fabrication methods for fiber-reinforced MMC's complex
- service experience limited

Numerous combinations of matrices and reinforcements have been tried since work on metal matrix composites began in the late 1950's. The most mature system consists of aluminum reinforced with boron fibers, which dates from the 1960's. In the following section, we discuss the reinforcements and matrices which are of greatest interest at this time. However, we emphasize that we are in the infancy of this technology, and other important systems undoubtedly will emerge.

REINFORCEMENTS

Metal matrix composite (MMC) reinforcements can be divided into five major categories: continuous fibers, discontinuous fibers, whiskers, particulates and wires. With the exception of wires, which are metals, reinforcements generally are ceramics.

Key continuous fibers include boron, graphite (carbon), alumina, and silicon carbide.

Boron fibers are made by chemical vapor deposition (CVD) on a tungsten or carbon core. These relatively thick monofilaments are available in 4.0, 5.6, and 8.0 mil diameters. To retard reactions that can take place between boron and metals at high temperature, fiber coatings of silicon carbide or boron carbide are sometimes used.

Silicon carbide monofilaments are also made by a CVD process, typically on a carbon core.

A multifilament yarn, designated as silicon carbide by its manufacture is also commercially available. However, this material, made by pyrolisis of organometallic precursor fibers, is far from pure silicon carbide, and its properties significantly different from those of monofilament silicon carbide.

Continuous alumina fibers are available from at least two suppliers. Properties of the several types of fibers are significantly different.

The major discontinuous fiber reinforcements at this time are alumina and alumina-silica. The latter are produced from kaolin. Both originally were developed as insulating materials.

The major whisker material is silicon carbide. The leading U.S. commercial product is made by pyrolysis of rice hulls.

Silicon carbide and boron carbide particulate reinforcements are obtained from the commercial abrasives industry. Silicon carbide particulates are also produced as a byproduct of the whisker process.

A number of metal wires including tungsten, beryllium, titanium, molybdenum have been used to reinforce metal matrices. The most important wire reinforced composites at this time are superconducting materials such as niobium-titanium and niobium-tin in a copper matrix, and tungsten wire/superalloys.

The reinforcements cited above are the most important at this time. Numerous others have been tried over the last thirty years, and others undoubtedly will be developed in the future.

MATRIX MATERIALS AND KEY COMPOSITES

A wide range of metallic alloys have been used as matrices. The most important at this time are based on aluminum, titanium, magnesium, copper and superalloys.

The most important MMC systems at this time are:

Aluminum Matrix

- Continuous fibers: boron, silicon carbide, alumina, graphite
- Discontinuous fibers: alumina, alumina-silica
- Whiskers: silicon carbide
- Particulates: silicon carbide, boron carbide

Magnesium Matrix

- Continuous fibers: graphite, alumina
- Whiskers: silicon carbide
- Particulates: silicon carbide, boron carbide

Titanium Matrix

- Continuous fibers: silicon carbide, coated boron
- Particulates: titanium carbide

Copper Matrix

- Continuous fibers: graphite
- Wires: niobium-titanium, niobium-tin
- Particulates: silicon carbide, boron carbide, titanium carbide

Superalloys Matrices

- Wires: tungsten

CHARACTERISTICS AND DESIGN CONSIDERATIONS

The properties of metal matrix composites generally differ considerably from those of monolithic (unreinforced) metals and polymer matrix composites. In this section, we consider the key features of MMC's, and how they influence designs.

Factors influencing the properties of a MMC include:

- reinforcement properties, form and geometric arrangement
- matrix properties
- reinforcement-matrix interface properties
- residual stresses arising from the thermal and mechanical history of the composite
- possible degradation of the reinforcement resulting from chemical reactions at high temperatures and mechanical damage from processing, impact, etc.

Monolithic (unreinforced) metals tend to be isotropic, that is, to have the same properties in every direction. However, some processes, such as rolling, can impart anisotropy, so that characteristics vary with direction. The stress-strain behavior of monolithic metals is typically elastic-plastic. Most structural metals have considerable ductility and fracture toughness.

The most important structural polymer matrix composites (PMC's) are reinforced with straight, parallel, continuous fibers or with fabrics. The most important reinforcing fibers are E-glass, S-2 glass, graphite (carbon) and aramid ("Kevlar" 49).

Epoxies are the most important resin systems at this time. There is considerable interest in polymers with higher temperature capability, such as polyimides, bismaleimides, etc.

Polymer matrix composites are strongly anisotropic. They are strong and stiff parallel to the fiber direction, but their stiffness and strength are low perpendicular to it. PMC's do not yield elastically, and their stress-strain curves are generally linear to failure. An exception is when transverse cracking in some plies causes a "knee" in the curve, with a reduction in secondary modulus.

Particulate-reinforced metal matrix composites, like monolithic metals, tend to be isotropic. However, the presence of brittle reinforcements and perhaps of metal oxides, tend to reduce their ductility and fracture toughness. Continuing work on these materials may reduce some of these deficiencies.

The properties of materials reinforced with whiskers depends strongly on their orientation. Randomly-oriented whiskers produce an isotropic material. However, processes such as extrusion can orient whiskers, resulting in anisotropic properties. The presence of whiskers also reduces ductility and fracture toughness, as do particulates.

Metal matrix composites reinforced with aligned fibers have anisotropic properties. They are stronger and stiffer in the direction

of the fibers than perpendicular to them. However, the transverse strength and stiffness of unidirectional MMC's (materials having all fibers oriented parallel to one axis) are frequently great enough for use in components such as stiffeners and struts. This is one of the major advantages of MMC's over polymer matrix composites which can rarely be used without transverse reinforcement.

As the modulus and strength of metals is significant with respect to that of most reinforcing fibers, their contribution to composite behavior is important. The stress-strain curves of MMC's often show significant nonlinearity resulting from yielding of the matrix.

Another factor which has a significant effect on the behavior of fiber-reinforced metals is the frequently large difference in coefficients of expansion between the two constituents. This can cause large residual stresses in composites when they are subjected to significant temperature changes. In fact, during cooldown from processing temperatures, matrix thermal stresses are often severe enough to cause yielding. Large residual stresses can also be produced by mechanical loading.

Although fibrous MMC's may have stress-strain curves displaying some nonlinearity, they are essentially brittle materials, as are polymer matrix composites. In the absence of ductility to reduce stress concentrations, joint design becomes a critical design consideration. Numerous methods of joining MMC's have been developed, including metallurgical and polymeric bonding and use of mechanical fasteners.

FABRICATION METHODS

Consideration of fabrication methods is an important part of the design process for all structural materials, and metal matrix composites (MMC's) are no exception. Considerable work is under way in this critica area, and significant improvements in existing processes and development of new ones appears likely.

Fabrication methods can be divided into two major categories, primary and secondary. Primary fabrication methods are used to create the metal matrix composite from its constituents. The resulting material may be in a form that is close to the desired final configuration, or it may require a considerable amount of additional processing, called secondary fabrication, such as forming, rolling, metallurgical bonding, machining, etc. The processes used depend on the type of reinforcement and matrix.

A critical consideration is that reactions between reinforcements and matrices can occur during primary and secondary processing at the high temperatures required to melt and form metals. This imposes limitations on the kinds of constituents that can be combined by the various processes Sometimes, barrier coatings can be successfully applied to reinforcements, allowing them to be combined with matrices that otherwise would be too reactive. For example, the application of a coating such as boron carbide permits the use of boron fibers to reinforce titanium. (Potential reactions between matrices and reinforcements, even coated ones, is also an important criterion in evaluating the temperatures and corresponding lengths of time to which MMC's may be subjected in service).

In the following discussion, we examine briefly some of the more important primary and secondary fabrication methods used with the various forms of reinforcements, metal wires, continuous fibers, discontinuous fibers, whiskers and particulates.

Fibers produced in the form of relatively large diameter monofilamen such as boron and silicon carbide, have been incorporated into metal matrices by hot pressing a layer of parallel fibers between foils to create what is often called a monolayer tape. In this operation, the metal flows around the fibers and diffusion bonding occurs. The same procedure can be used to produce diffusion bonded laminates having layers of fibers oriented in specified directions to meet stiffness and strength requirements for a particular design. In some instances, laminates are produced by hot pressing monolayer tapes in what can be considered a secondary operation.

Monolayer tapes can also be produced by plasma spraying metals on collimated fibers, followed by hot pressing.

Structural shapes can be fabricated by creep forming diffusion bonded laminates in a die. An alternate process is to place fibers and unbonded foils in a die and hot press the assembly.

The boron/aluminum struts used on the space shuttle are fabricated from monolayer foils which are wrapped around a mandrel and hot isotatica pressed to diffusion bond the foil layers together and, at the same time, to diffusion bond the composite laminate to titanium end fittings.

Metal matrices can be cast, or infiltrated, into a fabric or pre-arranged fibrous configuration called a preform. Frequently, an organic binder material is used to hold the fibers in position during infiltration, and is subsequently removed. Infiltration is frequently carried out under vacuum, pressure, or both. Pressure infiltration, which promotes wetting of the fibers by the matrix, is often called squeeze casting.

Casting methods appear to have great promise for low cost fabrication. It is believed that Toyota produces its fiber reinforced aluminum diesel engine pistons using a preformed fiber ring in a squeeze casting process.

At the current time, the most common method used to make graphite/aluminum and graphite/magnesium composites is first to pass the yarn through a furnace to burn off any sizing that may have been applied. Next it goes through an apparatus that applies by a chemical vapor deposition process a coating of titanium and boron which promotes wetting by the matrix. Then it immediately passes through a bath of molten metal producing an infiltrated bundle of fibers known as a "wire". Plates and other structural shapes are produced in a secondary operation by placing the wires between foils and pressing them, as is done with monofilaments. Recent development of "air stable" coatings permits use of other infiltration processes, such as casting, eliminating the need for the use of "wires" as an intermediate step.

A particularly important secondary fabrication method for titanium matrix composites is superplastic forming-diffusion bonding (SPF/DB).

To reduce fabrication costs, continuous processes, such as pultrusion and hot roll bonding are being developed.

At this time, most whisker- and particulate-reinforced metal matrix composites in the U.S. are made by mixing meta powders and reinforcements together in a liquid, which is subsequently removed. Mixtures have also been produced by use of ball mills. The mixture is then outgassed and hot pressed to form a billet. Secondary processes are similar to those for monolithic metals, including rolling, extrusion, spinning, forging, creep forming and machining. The latter poses some difficulties because the reinforcements are very hard.

Work is also underway to develop potentially low cost casting processes for particulate and whisker reinforcements.

END

FILMED

1-86

DTIC